International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 2, Apr 2018, 671-676

CFD ANALYSIS ON BUBLE GROWTH AND BUBBLE DEPARTURE IN POOL BOILING

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ABSTRACT

The process of bubble nucleation, growth and detachment are simulated using volume fraction method. As the bubble grows to a certain size, it will eventually detach from an active nucleation site, especially for the case of a pool boiling of a horizontal wall. Numerical results are compared with Distilled water and with Nano fluid of different concentrations. It is concluded that the departure diameter decreases as the wall superheat decreases, while the growing time increases.

KEYWORDS: Bubble Growth & Bubble Departure

Received: Feb 03, 2018; **Accepted:** Feb 24, 2018; **Published:** Mar 13, 2018; **Paper Id.:** IJMPERDAPR201878

Original Article

1. INTRODUCTION

Boiling flows are ubiquitous in the energy and processing industries due to the fact that phase change processes are an efficient way to transport heat. Bubble nucleation, growth and detachment are inherently complex.

The Bubble Nucleation, Growth and Detachment from a wall surface can be simulated using VOF method, Lagrangian approach**.** Y. Ose et al [5] described that Volume of Fluid (VOF) Method is the most popular volume capturing procedure based on the transport equation of VOF (volume of fluid). This uses a field, that contains information about the volume fraction of one of the phases in a numerical cell and which is convectively transported with the Eulerian velocity fields. The volume fraction field has a piece-wise value at the position of the interface and

Yikun Wei et al [6] in his work assess the bubble nucleation, growth and detachment, a simulation of bubble detachment from a wall surface. As time evolves, the bubble gradually grows due to the heated surface. Due to the gravity and the density difference, the bubble experiences an upward buoyancy force which leads to its shape deformation and a lift-off from the wall surface. Once the bubble migrates away from the wall, its shape deforms again due to the balancing actions of the buoyancy and the viscous drag forces from the surrounding liquid and Young Il cho et al [7] carried work using various models, in order to predict a relation of Bubble lift-off Diameter and Frequency in vertical sub cooled boiling flow. From experiment, they had taken 134 recordings and the relation between bubble lift-off diameter and bubbles raising frequency was evaluated. And, they concluded that both of these parameters compute each other in consuming the thermal energy from the heated surface.

1.1 Thermal Properties of Nano Fluids

Thermal Properties are important in order to simulate the heat transfer of the nano fluids. The following correlations, which are well accepted in the literature, were used to calculate the thermal properties of the nanofluids.

The density (ρ) of the Nanofluids is given by

$$\rho_{nf} = (1-\alpha)\rho_{bf} + \alpha\rho_{np}$$

The heat capacity (*Cp*) of the nano fluids was calculated by using the correlation

$$(\rho C_p)_{nf} = (1-\alpha)\,(\rho C_p)_{bf} + \alpha(\rho C_p)_{np}$$

The thermal conductivity (*k*) of the Nanofluids is calculated as

$$K_{nf} = K_{bf}\,[1 + 1.0112\alpha + 2.4375\,\alpha\,(47/ds) - 0.02488\alpha\,(Ks/0.613)]$$

The viscosity (μ) of nano fluid is calculated as

$$\mu_{nf} = (1 + 2.5\alpha + 6.2\alpha^2)\,\mu_{bf}$$

Where, the subscript **nf** refers to nano fluid, **bf** to base fluid, **np** to nanoparticle and **α** indicates the particle volume fraction.

Calculated Thermal properties are used in fluent as nano fluid properties

1.2 Model & Meshing

The ICEM-CFD software is used to create the structured, two-dimensional mesh for the simulation.

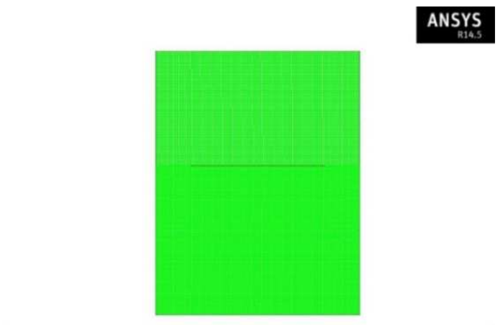

Figure 1.2: 1- 2-D Pool Boiling Model

1.3 Bubble Growth and Departure Timings

The growth of the bubbles and the bubble motion near the heated surface were recorded in computational fluid dynamics and compared with experimental bubble growth. Dimensions of a bubble were measured by counting the number of pixels in a symmetric bubble image. A physical dimension of 1mm corresponds to 30 pixels, i.e. 1 pixel in the image corresponds to 0.033 mm.

Bubbles of vapour are formed at certain locations on the solid surface. These grow in size, detach from the solid surface and rise to the liquid surface. At the peak, heats flux the bubbles coalesce and blanket the surface with a vapour film.

In CFD analysis given below, a unity value of the Volume fraction corresponds to a full element occupied by the fluid, and a zero value indicates an empty element containing no fluid (or vapour). The volume fraction value between zero and one indicates that the corresponding element is the partial element.

1.4 Bubble Growth and Departure Timings for Distilled Water

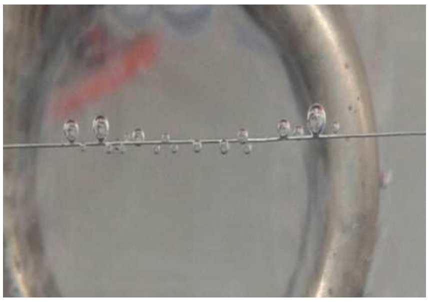

Figure 1.4.1 (a): Experimental Image of Bubble Departure Over Heater Surface

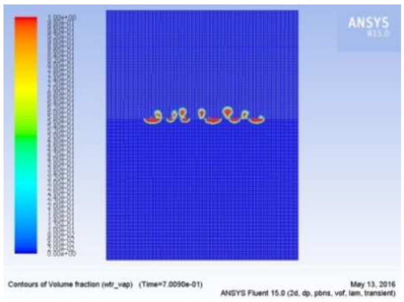

Figure 1.4.1 (b): Contour of Bubble Departure Over Heater Surface

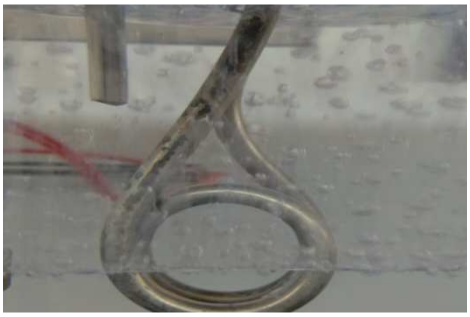

Figure 1.4.1 (c): Experimental Image of Bubble Growth Over Heater Surface

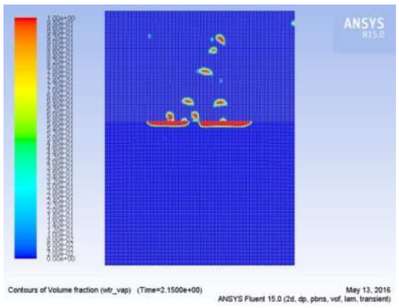

Figure 1.4.1 (d): Contour of Bubble Growth Over Heater Surface

The figure 1.4.1 (a) & (b) shows the comparison between experimental and CFD analyses that bubble, which arise over the heating surface for distilled water. The time 0.7 sec in figure 1.4.1 (b) indicates the timing that the bubble gets detached from the surface. Figure 1.4.1 (c) & (d) represents the bubble growth over the surface of wire after 2.15 seconds.

1.5 Bubble Initial Growth in Nano Fluids for Different Concentrations

For TiO_2

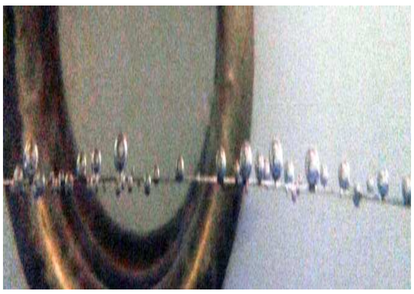

Figure 1.5.1 (a): Experimental Image of Bubble Over Heater Surface for TiO_2(0.01 g/lt)

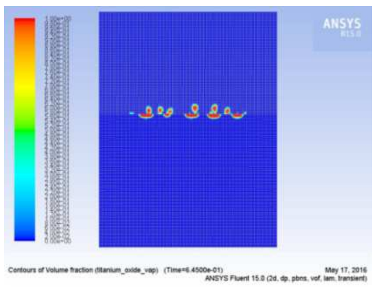

Figure 1.5.1 (b): Contour of Bubble Departure Departure Over Heater Surface for TiO_2(0.01 g/lt)

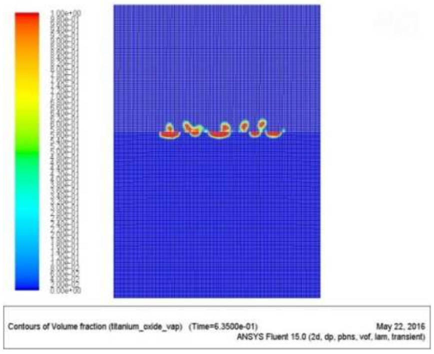

Figure 1.5.1 (c): Contour of Bubble Departure Over Heater Surface for TiO_2(0.1 g/lt)

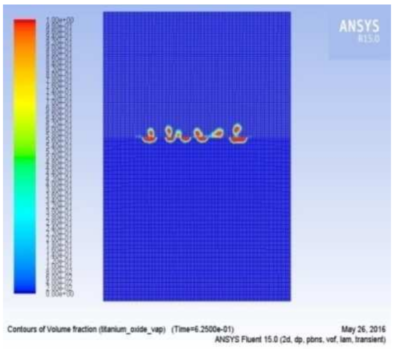

Figure 1.5.1 (d): Contour of Bubble Departure Over Heater Surface for TiO_2(1 g/lt)

The Figure 1.5.1 (a) & (b) shows comparison of initial bubble detachment in experimental and in cfd analysis part for TiO_2 0.01 g/lt. Whereas, Figure 1.5.1 (c) & (d) shows initial bubble detachment for TiO_2 0.1 g/lt and 1 g/lt, respectively. For TiO_2 0.01,0.1,1 g/lt the bubble departure timing found to 0.645,0.635,0.625 seconds, respectively. Bubble Diameter for detaching bubble was found to be 0.396mm, 0.429 mm, 0.462 mm for TiO_2 0.01g/lt, 0.1 g/lt and 1 g/lt respectively.

For MgO

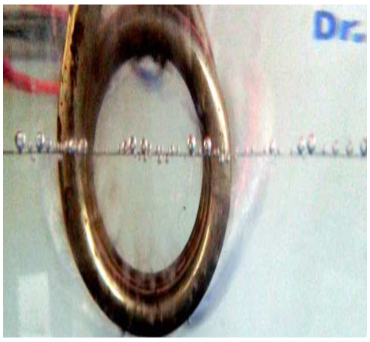

Figure 1.5.2 (a): Experimental Image of Bubble Over Heater Surface for MgO(0.01 g/lt)

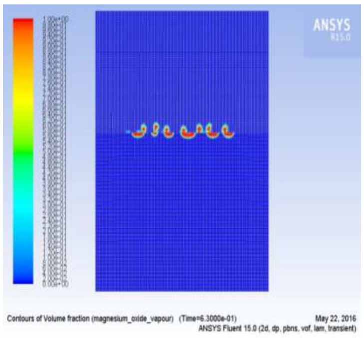

Figure 1.5.2 (b): Contour of Bubble Departure Departure Over Heater Surface for MgO(0.01 g/lt)

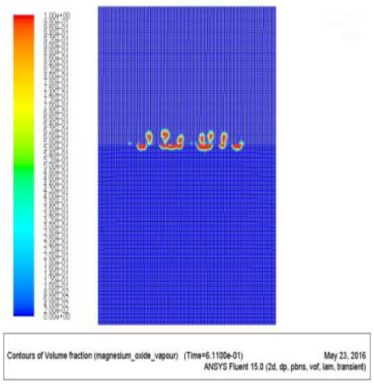

Figure 1.5.2 (c): Contour of Bubble Departure Over Heater Surface for MgO (0.1 g/lt)

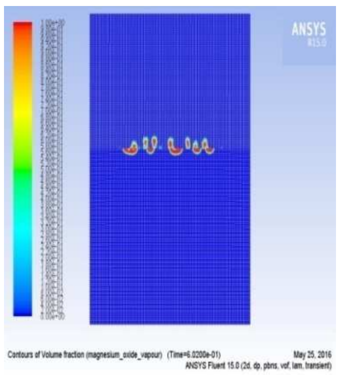

Figure 1.5.2 (d): Contour of Bubble Departure Over Heater Surface for MgO (1 g/lt)

The Figure 1.5.2 (a) & (b) shows comparison of initial bubble detachment in experimental and in cfd analysis part for MgO 0.01 g/lt. Whereas, Figure 1.5.2 (c) & (d) shows initial bubble detachment for MgO 0.1 g/lt and 1 g/lt

respectively. For MgO 0.01,0.1,1 g/lt the bubble departure timing found to 0.63,0.611,0.602 seconds respectively. Bubble Diameter for the detaching bubble was found to be 0.297mm, 0.33mm, 0.396 mm for TiO_2 0.01 g/lt, 0.1 g/lt and 1 g/lt, respectively.

Table 1: Computational Simulation Result of Pool Boiling

	Bubble Initial Departure Timing (in Seconds)	Bubble Rised in Second Cycle (in Seconds)	Bubble Wait Time(T_{wait})	Frequency of Bubble Generation(f) F= 1/T_{wait}
Distilled Water	0.564	0.805	0.241	4.14
TiO_2 0.01 g/lt	0.625	0.856	0.231	4.33
TiO_2 0.1 g/lt	0.635	0.808	0.173	5.7803
TiO_2 1g/lt	0.7009	0.8569	0.156	6.41
MgO 0.01 g/lt	0.602	0.89	0.288	3.473
MgO 0.1g/lt	0.63	0.827	0.197	5.076
MgO 1 g/lt	0.611	0.7935	0.1825	5.48

Waiting time t_{wait} is defined as the time between bubble departure and the corresponding to the next bubble at the same nucleation site.

From the above discussion, it is clear that the Diameter of detaching bubble (lift-off diameter) decreasing with the increase of volume concentration of nanoparticles i.e. directly proportional to the increase of heat flux, the frequency increasing very steeply with the increase of heat flux. Observing Table 4.9.1, it can be concluded that the bubble lift-off diameter and the bubble nucleation frequency has a stochastic feature in nature, and they compete with each other for the consumption of the thermal energy from the heated surface.

The bubble nucleation frequency times, the square of the bubble lift-off diameter ($f \times D_b^2$) showed clearer tendency with the change of heat flux. Therefore, $f \times D_b^2$ could be one promising parameter to explain the bubble nucleation and the bubble lift-off in natural convective pool boiling phenomenon. It is worthwhile to mention that the bubble nucleation frequency times and the square of the bubble departure diameter ($f \times D_b^2$) was constant for thermodynamic region in pool boiling systems.

CONCLUSIONS

To assess the bubble nucleation, growth and detachment, a simulation of bubble detachment from a wall surface is carried out.

- The bubble growth in a pool boiling in water and nano fluids was studied in Computational Fluid Dynamics and the effect of heat flux on bubble dynamics during nucleate pool boiling heat transfer in saturated water & Nanofluid was studied numerically.
- Pool boiling at a heated wall has been simulated by an Euler/Euler description of two-phase flow (VOF model). The measured vapour bubble size profiles show a decrease in detachment of the bubble size & increase in frequency, and they compete with each other for the consumption of the thermal energy from the heated surface.
- Overall, CFD results confirm that the great potential of the Euler/Euler two-phase flow (VOF model) for the simulation of pool boiling that is useful to industrial applications.

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